

*Reprinted from Proceedings of Special Conference  
"Computer Applications in Water Resources"  
WR Div., ASCE/Buffalo, New York  
June 10-12, 1985*

# EVALUATING WATER POLICY OPTIONS BY SIMULATION

Ann W. Peralta, Richard C. Peralta, A.M., and Keyvan Asghari\*

## ABSTRACT

Computer simulation models are used to predict the effects of three sample water policy decisions on selected conjunctive water use/sustained groundwater yield strategies for the Arkansas Grand Prairie. The three applications illustrate the facility of the target objective approach in providing an interface for legal, economic and engineering analysis. The approach is used to evaluate potential water management decisions at the judicial, legislative and water management district levels.

## INTRODUCTION

Water resources management requires consideration of physical, legal and economic realities. Too often, attempts by legislators, judges and administrators to manage the physical environment result in laws that are physically impossible (or nearly impossible) to implement. A Colorado Act illustrates this problem.

The Water Right Determination and Administration Act of 1969 defined the water policy of Colorado as the integration of "the appropriation, use and administration of underground water tributary to a stream with the use of surface water in such a way as to maximize the beneficial use of all the waters of this state." As Hubert Morel-Seytoux, et al (7) point out

"...the lawmaker may not have fully realized the meaning of the 'zeroth law' of Operations Research. It is not possible to maximize the beneficial use of surface water and to maximize the beneficial use of groundwater at the same time. It is possible, however, to maximize the beneficial use of surface water while maintaining a given level of beneficial use of groundwater, or vice versa. Or, more significantly, it is possible to maximize an overall beneficial use of groundwater and surface water. What this overall objective function should be is not precisely spelled out by the Act."

\* Research Associate, Arkansas Water Resources Research Center; Assistant Professor and Graduate Research Assistant, Agricultural Engineering Department, respectively, University of Arkansas, Fayetteville, Arkansas, U.S.A.

Furthermore, if the Colorado legislature really intended to "integrate" groundwater and surface water "appropriations, use and administration", then the creation of separate institutional entities to govern groundwater, as provided for in the Act, is not a logical move (5). Tension, competition and conflict accompany interagency efforts to coordinate management (16). For this reason, achieving conjunctive use of ground and surface water is more likely when both are managed by one agency (8,9). Numerous other deficiencies of the Act (which will not be discussed here) have been enumerated from the perspectives of a political scientist (5) and of an engineer (7).

As the preceding indicates, formulating adequate water laws and rules is not easy. Besides the uncertainties of nature, the legislator, judge, or administrator must also consider social and political realities. Unfortunately, true interdisciplinary analyses of potential effects of water laws are rarely made until after legislation is passed or court decisions are rendered. Those responsible for determining public water policy are often unaware of available technological tools or are uncertain about how such tools can be used. Perhaps because of groundwater's hidden nature, this lack of awareness is nowhere more apparent than in efforts to provide a legal framework for groundwater management. The development of laws governing groundwater use has usually preceded an understanding of an aquifer's characteristics. As a result, perfected legal rights may bear scant resemblance to an aquifer's actual ability to sustain the legally permissible rate of pumping (12).

One major difficulty in utilizing the best existing technology to analyze proposed policy changes lies in defining an interface between legal, economic and physical systems (15). Operationalizing terms, for example, translating legal terms into constraints suitable for inclusion in a computer groundwater simulation model, requires either a working knowledge of both law and engineering or cooperation and communication between practitioners of both disciplines (4). Even choosing units of measure can be a source of misunderstanding. Gallons were selected as the units of measure for water use in a draft version of a proposed Arkansas water code. One water resources engineer spent considerable time explaining to a legislative subcommittee why gallons would not be a feasible unit in application. (Another engineer observed in 1909 that "measuring water to irrigators in gallons would be like selling coal to railroads by the ounce" <6>.) Considering the general lack of familiarity with basic engineering principles in our society, it is not surprising that highly technical methodologies require some elucidation. The water resources engineer is obligated to make his work accessible and understandable if he hopes to facilitate the systematic design of water laws (7).

This paper describes efforts to accomplish this goal for the Arkansas Grand Prairie, a major rice, soybean, and aquacultural production area. A shallow Quaternary aquifer supplies more than half of the Grand Prairie's irrigation and other water needs.

Average annual withdrawals from the aquifer have long exceeded recharge and a number of wells have become unusable (13). In recent years, concern over (i) the 1980 drought and (ii) dropping water levels has provided impetus for the formation of an irrigation district in the Grand Prairie and for efforts by the State legislature to reformulate and codify Arkansas water law (9). Computer simulation models are utilized to predetermine the effects of three sample policy decision scenarios on Grand Prairie Quaternary water users.

#### TARGET LEVEL AND TARGET OBJECTIVE APPROACHES

Quantitative groundwater models have traditionally been used to predict water levels that result from given pumping rates. They are not designed to calculate the annual spatial distribution of pumping which will maintain groundwater at desired, or target, elevations. A different modeling approach has been developed to determine groundwater pumping that will maintain preselected target levels (12,13). The utility of the target level approach for maintaining 1982 Grand Prairie Quaternary water levels (as the chosen target levels) and the legal feasibility of using the approach with only minor modifications to Arkansas water law has been demonstrated (12,13).

A refinement of the target level approach allows the investigator to choose a policy objective (10,11) rather than a specified potentiometric surface, such as the 1982 water levels previously reported. This target objective approach allows the simultaneous determination of (i) the optimal steady state potentiometric surface that best achieves the chosen objective and (ii) the conjunctive use/sustained yield strategy that will create and maintain that surface. Models with this capability are valuable tools in the a priori analysis of water policy decisions before implementation. This paper illustrates the ramifications of three alternative policy decisions using the target objective approach.

#### TESTED POLICIES AND RESULTS

##### The Court-Imposed Correlative Rights Scenario

As is true in most humid eastern states, water rights in Arkansas are based on the old English Common Law (a,b,c,d,f,i,j) and are delineated on a case by case basis (9). Under the common law, the right to use surface water is contingent upon ownership of riparian lands—lands directly adjacent to surface water—and is an actual part and parcel of the soil (h,k). Similarly, the right to use groundwater is incident to ownership of land overlying a groundwater basin (f,g).

The "reasonable use" rule is the standard for both surface and groundwater use in Arkansas (d,f). Riparian or overlying

owners share a co-equal right to make reasonable use of the water supply as long as such use does not unreasonably interfere with the rights of similarly situated users (d). No user "has priority in use of water in derogation of another's rights" (k).

An owner of land overlying groundwater in Arkansas has the legal right to use the water "to the full extent of his needs if the common supply is sufficient, and to the extent of a reasonable share thereof, if the supply is so scant that the use by one will affect the supply of other overlying users" (f). In times of scarcity, the California correlative rights doctrine governs, allowing each overlying landowner a proportionate or prorated share of the available supply (e,f). In a number of California cases, the correlative rights doctrine has been interpreted by the courts to require: (i) adjudication of a groundwater basin, (ii) determination of a safe yield, and (iii) assignment of rights to a share of the available supply based on extraction prior to adjudication (1,7).

Current pumping from the Quaternary aquifer underlying the Grand Prairie is such that the use by one does "affect the supply of other overlying users". The fact that a growing number of wells are becoming unusable due to falling water levels and inadequate saturated thicknesses is ample proof of this (14). In the absence of effective water management, it is probably only a matter of time before an injured water user initiates litigation that will result in a court-ordered prorated reduction of pumping to achieve a (safe) sustained yield. The question is, then, what across-the-board percentage reduction of current extraction is necessary in order to attain a sustained yield from the aquifer?

Utilizing the target objective approach, as described by Peralta, et al (11), the consequences of a strict application of the correlative rights doctrine can be predicted. Under a court ordered proportionate reduction, only 14% of 1982 pumping would be allowed in each cell. This 86% reduction in Quaternary groundwater use would result in a short term net economic reduction of over \$8,000,000 per year for rice, irrigated soybeans and aquaculture. Being able to predict the result of delaying groundwater management decisions (and by default turning the courts into water management agencies) makes the need for active management measures obvious. It has been demonstrated that, over the long term, Quaternary groundwater can supply less than half of the demands currently being placed on the aquifer (11). This inability makes the need for conjunctive use of ground and surface water evident.

#### Two Least-Cost Conjunctive Use/Sustained Yield Policy Scenarios

Two versions of a water code have been introduced in the 1985 Arkansas legislative session. One measure, House Bill 85 and Senate Bill 131, is a slight modification of the comprehensive water code proposed to (and rejected by) the 1983

legislature. The second, Senate Bill 33 and House Bill 126, is a slightly more modified version of the 1983 proposal. There are a number of differences between the two measures currently under consideration, but one common feature is the definition of legal water use as "reasonable beneficial use". Reasonable beneficial use is defined as "the use of water in such quantity as is necessary for economic and efficient utilization for a purpose and in a manner which is both reasonable and consistent with the public interest."

Operationalizing this definition for inclusion in a water resources simulation model requires agreement on certain assumptions. First, as discussed above, the reasonable use rule allows only those uses which are not "in derogation of another's rights" (k). Neither groundwater (f) nor surface water (d) users may unreasonably interfere with the rights of others. As a logical extension of this interpretation, uses which result in saturated thicknesses so thin that wells become unusable, may well be ruled "unreasonable". For an agricultural economy dependent on Quaternary groundwater, the economic results of exhausting the aquifer's usefulness would be catastrophic. Finally, mining which leads to excessive declines in the groundwater level may permanently damage the aquifer through compaction, lessening its future utility. Therefore, implementing a pumping strategy which guarantees a sustained yield "is both reasonable and consistent with the public interest."

Since Quaternary groundwater alone can meet less than half of the long term demand, conjunctive use of ground and surface water is a necessity (11). "Economic and efficient utilization for a purpose and in a manner which is both reasonable and consistent with the public interest", then, may be translated as a "least-cost conjunctive use/sustained yield strategy" for testing policy alternatives.

For these alternatives, the target objective approach (10) is used to minimize the cost of attempting to satisfy the pre-existing water needs for aquaculture, rice, and irrigated soybeans with ground water and supplemental diverted surface water. In performing the minimization, the model considers: (i) the cost per unit volume of Quaternary groundwater (based on the total dynamic head of a representative well in the center of each three mile by three mile cell in the study area); (ii) the cost per unit volume of diverted river water (in all cells to which diversion is feasible); and (iii) the opportunity cost—reduction in net economic return—per unit volume of unsatisfied water demand (in cells to which diversion of river water is not feasible). The model assumes that divertable surface water resources are adequate to completely satisfy demand not met by Quaternary groundwater in the cells to which surface water may be diverted.

The model output is a regional strategy consisting of the specified annual volumes of Quaternary groundwater and supplemental diverted surface water to be used in each cell. In

the least-cost conjunctive use/sustained yield strategy, there are some demands (water needs currently being supplied by mining the Quaternary aquifer) that cannot be met over the long term by Quaternary groundwater or diverted surface water) in the northern part of the Grand Prairie. Each of the following scenarios represents a policy designed to balance actual groundwater withdrawals in each cell with those specified in the optimal least cost strategy.

The alternate crop switch scenario.

The alternate crop switch scenario outlines a mechanism for reducing water demand in cells where water needs cannot be conjunctively met over the long term. To reduce demand, acreages are switched on a crop by crop basis from aquaculture, rice or irrigated soybeans to nonirrigated soybeans. The question is how to prioritize the crop switch. Aquaculture provides the highest net economic return per acre, but the lowest net economic return per acre-foot of water. Irrigated soybeans provide the lowest net economic return on a per acre basis, but the highest net economic return per acre-foot of water used. If crops are switched on the basis of the least loss in return per acre, irrigated soybean acreages are switched first to dryland soybeans, followed by rice, and aquacultural acreages are switched last. If, on the other hand, one wishes to minimize the reduction in net economic return per acre-foot of unsatisfied demand, then aquacultural acreages are switched to dryland soybeans first, followed by rice, and finally by irrigated soybeans. Table 1 shows a comparison of the two alternatives.

TABLE 1.—Impact of changing acreages to dryland soybeans.

	Minimizing loss in return per acre	Minimizing loss in return per acre-foot
Change from current acres Aquaculture	-2,980	-3,338
Change from current acres Rice	-7,643	-6,806
Change from current acres Irri. Soybeans	-4,555	-3,265
Change in net economic return (\$s)	-2,778,000	-2,705,000

Most regional economic analyses are performed on a per acre basis. That approach implicitly assumes that land is the limiting criteria. It is interesting to note in Table 1 that the reduction in net economic return is slightly less when the crop

switch is implemented on a per acre-foot basis. This suggests that in a sustained yield setting, water may be the limiting criteria and rules for strategy implementation may be at least as appropriately formulated on a per acre-foot basis.

The economic incentive/disincentive scenario.

Under the economic incentive/disincentive scenario, rebates and surcharges are utilized. The following example merely illustrates the utility of the target objective approach, and is not a policy recommendation. Assuming that economic considerations are the driving forces behind a water user's decision to use groundwater or surface water or to voluntarily switch to nonirrigated soybeans, the incentive (rebate) and the disincentive (surcharge) must be sufficient to motivate compliance with the conjunctive use/sustained yield strategy. Water has traditionally been unvalued or undervalued (2,7). Disincentives have, as a reflection of the societal devaluation of water, often been too small to have any significant effect upon water use patterns.

Orange County (California) Water District has successfully balanced the charge for overusing groundwater with the cost of importing supplemental surface water (3,9). The Orange County Water District Act authorizes the district to (i) determine whether an overdraft exists; and, if so, to (ii) "levy and assess a charge or replenishment assessment". The assessment varies according to the price of supplemental water, to insure that no water user has an economic incentive to overpump groundwater. The set of incentives and disincentives for the Arkansas Grand Prairie is necessarily different from the Orange County model. In Orange County, all needs are met through groundwater and purchased supplemental surface water. Unfortunately, it is not feasible to supply supplemental surface water to some cells in the Grand Prairie, so surcharges are calculated based on opportunity costs as well as the cost of diverted river water.

The cost of groundwater is a function of the total dynamic head at the center of each cell and corresponding maintenance and energy costs. The cost of not using groundwater in a cell is either the cost of delivering diverted river water to the field or the opportunity cost of converting from a current crop to dryland soybeans. If the unit cost of an alternative to groundwater is less than the cost of groundwater, then a rebate is offered, as needed, to encourage adequate pumping to maintain regionally desirable hydraulic gradients. In the sample simulation, rebates are never required in cells not receiving supplemental surface water. If the unit cost of alternatives is greater than the unit cost of groundwater, then a surcharge is levied for any pumping that exceeds desired annual volumes. Costs are calculated on an acre-foot basis and generally vary from cell to cell. The opportunity costs and surcharges are also different for each crop, since the net economic return per unit volume of consumed water varies from crop to crop.

It should be noted that after implementation of a sustained yield strategy, groundwater levels gradually evolve from current levels to the target objective surface. During this process, the cost of groundwater changes from year to year (as do rebates and surcharges) until the target surface is reached (10). The discussion in this paper is limited to determining rebate and surcharge rates for the first year of management, based on current data.

Rebates range up to \$9.80 per acre-foot in cells where diverted surface water is more costly than groundwater. Since there is no unsatisfied demand in these cells, rebates are the same for each crop. The purpose of the rebates is to insure that water users are not penalized for pumping more expensive groundwater to help maintain the regional optimal strategy, when less expensive diverted surface water is available.

Surcharges exist for all cells that do not qualify for rebates. Again, assuming current costs, surcharges in cells with available diverted surface water range up to \$17.89/acre-foot, although for most cells it is less than \$10/acre-foot. For cells without access to diverted surface water, the greatest surcharges are \$71.50/acre-foot for aquacultural use, \$96.50/acre-foot for rice irrigation, and \$122.60/acre-foot for soybean irrigation. Table 2 shows the maximum possible surcharges for 1985 water use.

Table 2.—Maximum Calculated Seasonal Surcharges

	Maximum Surcharge (\$/ac-ft)	Seasonal Water Use (ac-ft/ac)	Maximum Seasonal Surcharge (\$/ac)
Aquaculture	71.50	7	500.50
Rice	96.50	2	193.00
Irrigated Soybeans	122.60	0.4	49.00

The surcharges are of such magnitude that the profit of production would be eliminated, making it unlikely that producers would overpump groundwater. If dramatic increases in crop values occur after surcharge rates are fixed for the year, water users might wish to continue pumping at current rates. In such a case, some \$2,234,000 in total surcharge revenues would be generated.

#### CONCLUSIONS

Formulating appropriate water laws and rules is not easy. Besides the vagaries of nature, water policy decision makers must also consider the social and political ramifications of their

actions. Too often, judges, legislators and administrators are unaware of available technical tools for water management or are uncertain about how these tools can be used. Water resource engineers have the obligation not only to develop such tools, but to also make them accessible and understandable.

The paper presents applications of the target objective approach to regional water management. The approach is readily adapted to interdisciplinary analysis and provides an interface between legal, economic and engineering systems. It allows the simultaneous determination of (i) the optimal steady state potentiometric surface that best achieves the chosen regional objective and (ii) the conjunctive use/sustained yield strategy that will create and maintain that surface.

The applications represent possible policy choices made on the judicial, legislative and water management district levels. The potential for future use is not limited to research initiated within a single discipline, but to investigations in law, economics, political science and sociology as well as in engineering.

#### APPENDIX I. REFERENCES CITED

1. Anderson, T. L., Burt, O. R. and Fractor, D. T., "Privatizing Groundwater Basins", in Water Rights, Pacific Institute for Public Policy Research, San Francisco, Calif., 1983, pp.223-248.
2. Church, A. M., Conflicts Over Resource Ownership, D. C. Heath and Co., Lexington, Mass., 1982.
3. Dunbar, R.G., Forging New Rights in Western Waters, University of Nebraska Press, Lincoln, Nebraska, 1983, p.161
4. Flack, J. E., ed., Proceeding of the Conference on Interdisciplinary Analysis of Water Resource Systems, American Society of Civil Engineers, New York, N.Y., June, 1973.
5. Foss, P. "Institutional Arrangements for Effective Water Management in Colorado", Completion Report No. 88, Colorado Water Resources Research Institute, Fort Collins, Colo., 1978, p. 189.
6. Mead, E. Irrigation Institutions, The MacMillan Co., New York, N.Y., 1909, p. 101.
7. Morel-Seytoux, H. J., Young, R. A., Radosevich, G. E., "Systematic Design of Legal Regulations for Optimal Surface-Groundwater Usage—Phase I", Completion Report No. 53, Colorado Water Resources Research Institute, Fort Collins, Colo., 1973.
8. National Water Commission, Water Policies for the Future, U. S. Government Printing Office, Washington, D. C., 1973, p.235.
9. Peralta, A. "Alternative Institutional Arrangements for Water Management in Arkansas", The Winthrop Rockefeller Foundation, Inc., Little Rock, Arkansas, 1982.

10. Peralta, R. C. and Killian, P. J., "Optimal Regional Potentiometric Surface Design: Least-Cost Conjunctive Use/Sustained Groundwater Yield", In review for publication in Transactions, American Society of Agricultural Engineers.
11. Peralta, R. C., Killian, P. J., and Asghari, K., "Optimizing Sustained Groundwater Yields for Multiple Water Policy Options", In review for publication in Water Resources Bulletin, American Water Resources Association.
12. Peralta, R. C. and Peralta, A. W., "Arkansas Groundwater Management Via Target Levels", Transactions, American Society of Agricultural Engineers, Vol. 27, No. 6, 1984a, pp. 1696-1703.
13. Peralta, R. C. and Peralta, A. W., "Using Target Levels to Develop a Sustained Yield Pumping Strategy in Arkansas, a Riparian Rights State", Arkansas State Water Plan Special Report, Arkansas Soil and Water Conservation Commission, Little Rock, Arkansas, 1984b.
14. Peralta, R. C., Yazdanian, A., Killian, P. J., and Shulstad, R. N., "Future Quaternary Groundwater Accessibility in the Arkansas Grand Prairie--1993", Bulletin No. 877, Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas, 1985.
15. Poister, T. H., Public Program Analysis--Applied Research Methods, University Park Press, Baltimore, MD, 1978, pp.59-85.
16. Wright, D. S., Understanding Intergovernmental Relations, Duxbury Press, North Scituate, Mass., 1978.

#### APPENDIX II. LEGAL CASES AND STATUTES CITED

- a. Ark. Stat. Ann. 1-101.
- b. Boone v. Wilson, 125 Ark. 364, 188 S.W. 1160 (1916).
- c. Harrell v. City of Conway, 224 Ark. 100, 271 S.W. 2d 924 (1954).
- d. Harris v. Brooks, 225 Ark. 436, 283 S.W. 2d 129 (1955).
- e. Hudson v. Dailey, 156 Cal. 617, 105 (1909).
- f. Jones v. OZ-ARK-VAL Poultry Co., 228 Ark. 76, 306 S.W. 2d 111 (1957).
- g. Lingo v. City of Jacksonville, 258 Ark. 63, 522 S.W. 2d 403 (1975).
- h. Meriwether Sand and Gravel Co. v. State, 181 Ark. 216, 26 S.W. 2d 57 (1930).
- i. Scott v. Slaughter, 237 Ark. 394, 373 S.W. 2d 577 (1963).
- j. Taylor v. Rudy, 99 Ark. 128, 137 S.W. 574.
- k. Thomas v. LaCotts, 222 Ark. 171, 257 S.W. 2d 936 (1953).